EFFICIENT FIELD INSPECTION AND EVALUATION FOR CONCRETE BRIDGE DECK WITH ASPHALT OVERLAY

Jin-Won SUH, Ji-Young RHEE, Bon-Sung KU, Chang-Ho PARK, Jae-In SHIN, Byeong-Ju LEE

Structure Research Team

Korea Expressway & Transportation Research Institute

50-5 Sancheok-ri, Dongtan-myeon, Hwasung-si, Gyeonggi-do, Korea

jw_seo@ex.co.kr

ABSTRACT

Bridge decks are directly exposed to traffic loads and environmental factors, such as rain water and de-icing chemicals. For this reason, the deterioration of asphalt overlay and concrete deck is often observed. The main cause of deterioration of decks with asphalt overlay is the freeze-thawing action in the area where the concrete is saturated by water and de-icing salt according to the waterproof membrane damage. In this study, concrete bridge decks were evaluated by a road inspection system and a GPR system mounted on the vehicle. The GPR system can detect deteriorated locations of concrete decks under the asphalt overlay, even though the asphalt overlay may appear sound. Therefore, for efficient maintenance of concrete bridge decks, GPR examination needs to be accompanied with visual inspection.

1. INTRODUCTION

Bridge decks are directly exposed to traffic loads as well as environmental conditions like rain water and de-icing chemicals causing the freeze-thawing action. For this reason, bridge deck deterioration is a major problem for highway agencies and is one of the leading contributors to the number of deficient bridges.

In the past, the main damage cause of concrete bridge decks had been known as fatigue stress by repetitious vehicle loads. Accordingly, visual inspections have been conducted about cracking and efflorescence on the bottom of the decks. Recently, it is found that the main deterioration cause of concrete bridge decks with asphalt overlay is the freeze-thawing action in the area where the concrete was saturated by water and de-icing salt according to the waterproof membrane damage. That is to say, the damage of concrete decks are occurred in terms of the combined deterioration problems.[1)]

Such damage can only be identified after the deterioration symptoms came out on the overlay surface since severe damage had occurred in the concrete deck. So, it is difficult to identify such damage by

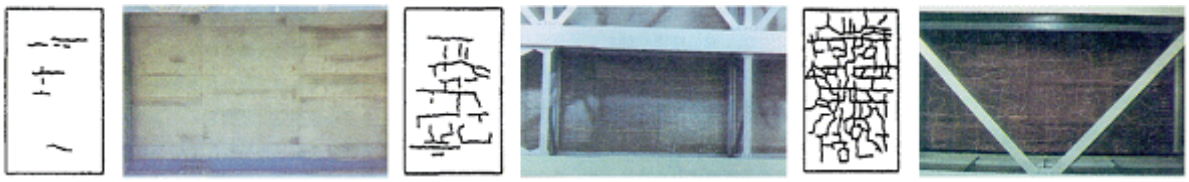
the visual inspection before it takes place. This not only causes structural safety issues but also increases the risk of traffic accidents and difficulties in the bridge maintenance.

For the purpose to solve the problems, the application of GPR system mounted on vehicle was studied as a tool to inspect the concrete bridge deck with asphalt overlay.

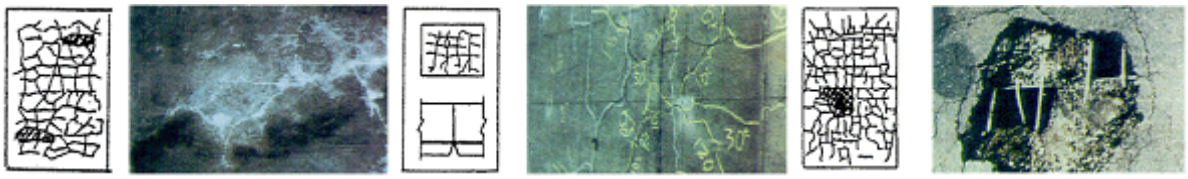
2. **DAMAGE IN BRIDGE DECKS**

2.1 **Damage in the past**

In case of the aged concrete bridge decks designed according to the Thin Plate Theory, cracks increase by fatigue stress according to the repetitious vehicle loads on the area where the initial damage had been occurred. Such cracking damage occurs over 6 stages as shown in Figure 1: ① cracks occur in one direction on the bottom of bridge deck ② cracks develop in two directions ③ alligator cracks are formed ④ efflorescence appears ⑤ the corners of cracks are worn and the crack width is getting wider ⑥ punch-out of concrete deck occurs.[2)]



(a) Stage 1 (b) Stage 2 (c) Stage 3



(d) Stage 4 (e) Stage 5 (f) Stage 6

Figure 1 Failure procedure of concrete decks in the past

2.2 **Damage at recent times**

Because the concrete bridge decks constructed in recent times are thicker than those of old bridges, the fatigue failure by vehicle loads hardly occurs. However, the large amount of de-icing salt used on expressways in wintertime had made the deteriorations of concrete decks under the asphalt overlay. The failure process of concrete decks follows next 5 stages: ① initial defect occurs in a overlay ② harmful chemicals and water penetrate ③ deteriorated cement paste permeates out on the overlay ④ internal deterioration progresses ⑤ concrete bridge deck punches out. This failure procedure is illustrated in Figure 2 and 3.

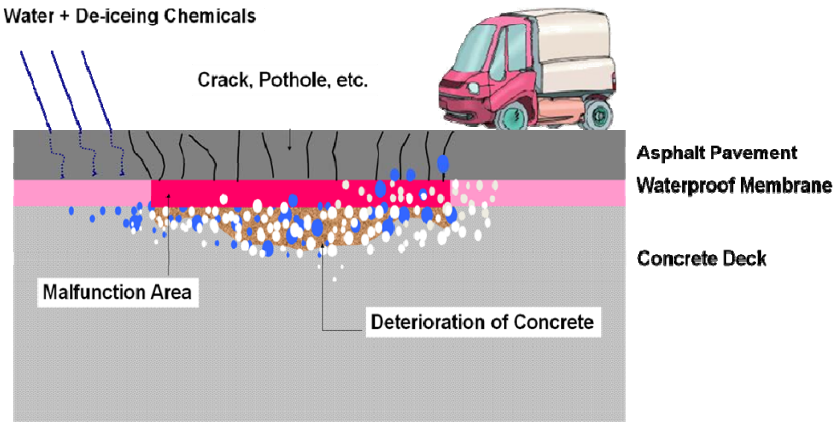


Figure 2 Deterioration overview of a concrete deck with an asphalt overlay

Figure 3 Deterioration procedures of concrete decks at recent times

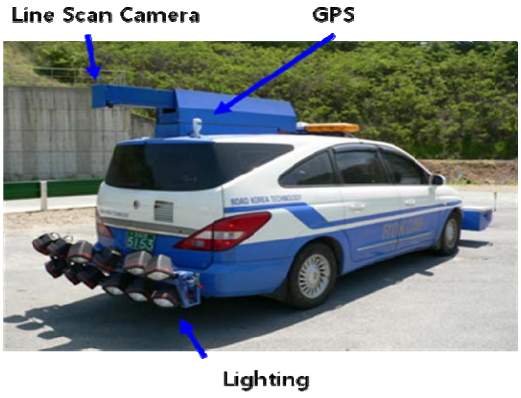
3. **CONDITION EVALUATION OF BRIDGE DECKS**

3.1 **Visual Inspection**

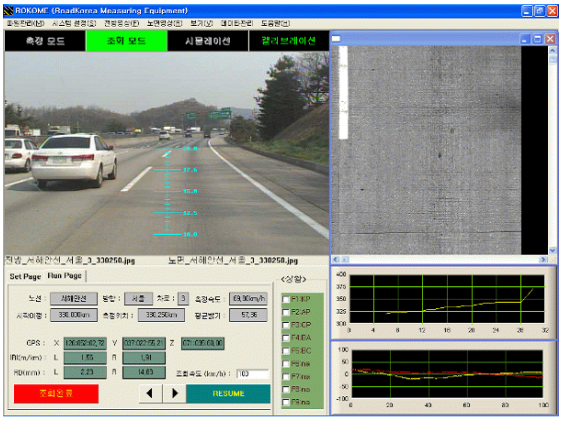
Currently, visual inspections are regularly being done on deck surfaces as preventative maintenance. In the past, deck surfaces were visually inspected and their condition grades were determined by the judgment of the inspector. Pictures of road surface photographed by a road inspection vehicle system allowed the quantitative analysis for several damage types to evaluate deck surfaces. As a result, the bridge surface conditions can be graded according to the criteria in Table 1. Figure 4 shows an example evaluated by the system.

Bridge surface inspections were conducted in 2007 and 2008. The conditions of these bridges were rated according to Table 1 and the result was summarized in Table 2.

As shown, the condition grades as an overall bridge were Grade "A" to "C" but the condition grades of only road surface of bridge were grade "a" to "e", which are relatively low in comparison to those of the overall bridge. This corresponds with the fact that the deck and overlay failures occur more frequently and their replacements takes place more quickly than other components of bridge members.



Picture 1 The road inspection vehicle system



Picture 2 A overview of operating software

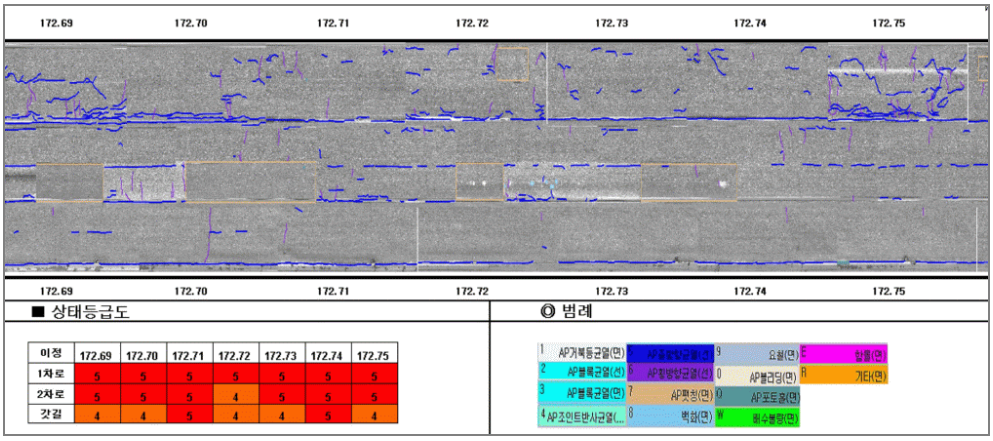


Figure 4 An inspection example achieved by the road inspection system

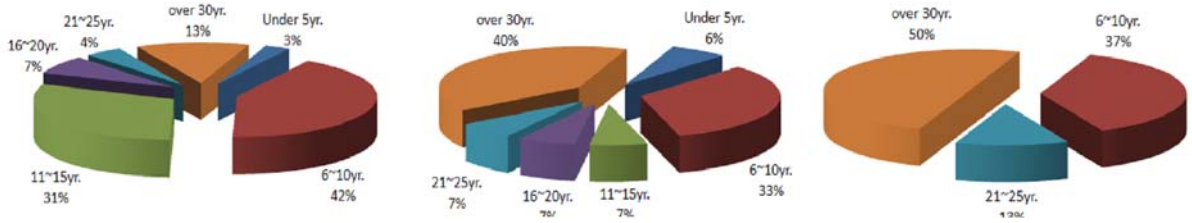
Table 1 Rating Criteria

Condition Grade	Deterioration ratio (%)
a	No harm
b	Less than 2
c	2 ~ 10
d	10 ~ 20
e	More than 20

Table 2 Condition grade of decks by visual inspection (unit : ea.)

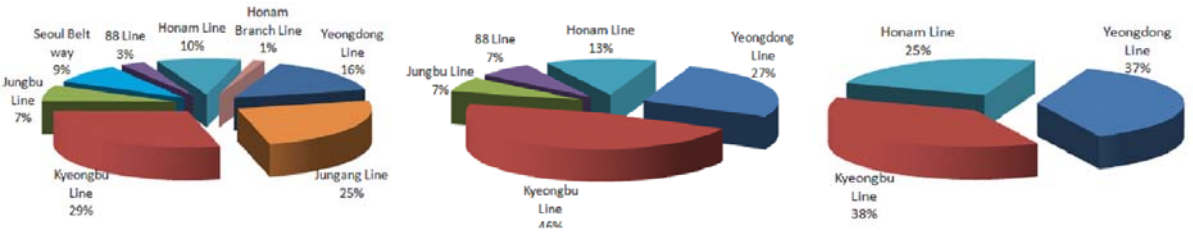
Condition Grade	2007 year		2008 year		Total	
	Bridge	Deck Surface	Bridge	Deck Surface	Bridge	Deck Surface
A	68	0	60	25	128	25
B	40	27	18	37	58	64
C	19	72	0	16	19	88
D	0	20	0	0	0	20
E	0	8	0	0	0	8
Subtotal	127	127	78	78	205	205

The number of bridge surfaces with condition grade "c", "d" and "e", which were required the deck repair, was approximately 57% of the total. A third of them were found in 6~10 years old bridge which are typically done the first repair of deck and overlay. Many young bridges with severe deck damage were located on the Yeongdong Expressway in High Mountains area where is snowy and cold. But the damage in bridge decks could be estimated from such visual inspection when inner concrete damage develops and is exposed on the overlay. In other words, an inspection of bridge surfaces can only identify the damage of the overlay. Another inspection was needed to identify the inner concrete deck condition. Therefore, bridge maintenance engineers want to get a technique that could inspect the inner condition of concrete deck independently of the overlay condition.



(a) Grade c (b) Grade d (c) Grade e

Figure 5 Condition grade according to bridge ages



(a) Grade c (b) Grade d (c) Grade e

Figure 6 Condition grade in each expressway line.

3.2 **Internal condition**

During the past 10 years, the inspection results of expressway bridge decks had been showed that extensive damage could occur on the top of concrete decks under the overlay even though the overlay surface had a good appearance. It is told that another inspection should be conducted to evaluate the inner concrete condition in addition to the inspection of the overlay appearance.

In the past, the asphalt overlay was removed to make an inspection of the concrete deterioration or core samples were extracted to survey the depth of damage. However, such methods are slow, not cost-effective and only partial inspection of the deck. And these methods also need any traffic lane closure. Thus, the GPR (Ground Penetrating Radar) system mounted on vehicle was applied to inspect the concrete decks under the overlay.

As shown in Figure 7, if rain water infiltrates at the deck concrete passing through the overlay, the moisture content of deck concrete increases. The more the water content of concrete increase, the higher its relative permittivity is. It is told that deck concrete with high relative permittivity is the area

deteriorated by freeze-thawing action because there is saturated with water and chemicals according to the damage of overlay and waterproof membrane. The relative permittivity of concrete deck can be obtained by GPR system. Figure 8 shows the result of the GPR survey performed on bridge decks under asphalt overlay. It illustrates the distribution of the relative permittivity of the concrete decks as a plane view. The dark areas in the figure represent the damaged areas which will be or are present.[3)]

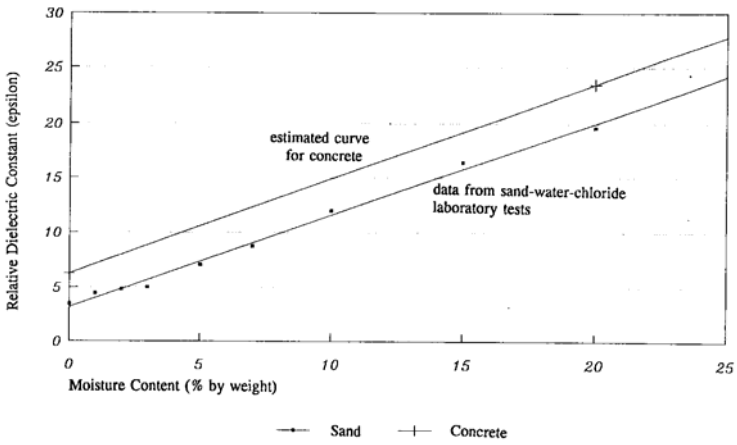
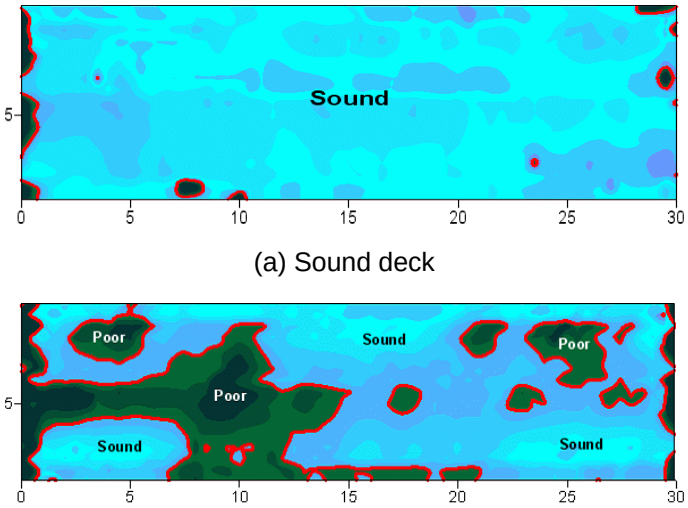


Figure 7 Relative dielectric constant versus moisture content

Picture 3 GPR vehicle system



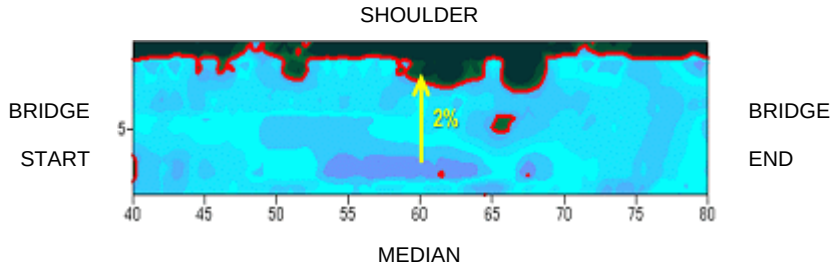
(a) Sound deck

(b) Deteriorated deck

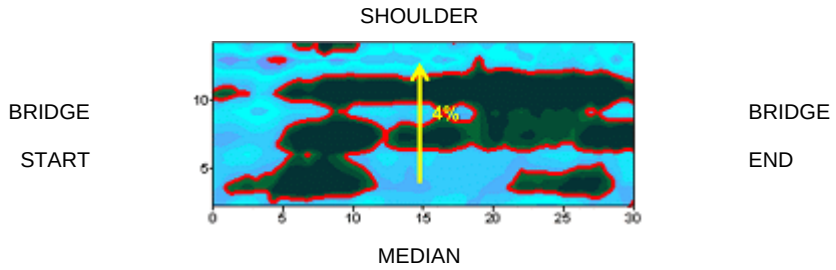
Figure 8 Example maps of relative permittivity of deck concrete under the pavement

32 bridge decks inspected in Article 3.1 were inspected and evaluated by GPR system. As the previous inspection, the condition grades were classified according to Table 1. The result showed that deteriorations of young bridge decks start at the locations next to drain gutters where are low in transverse direction and easily have some staying water. On the other hand, the damages of aged bridge decks appeared higher on the 2nd traffic lane where the overlay damage is begun by the repetitious heavy-vehicle loads. In other words, the followings can be told. For preventing the

premature failure of young bridge decks, the draining facilities should be maintained not to have the staying water. And for reducing the deck failure of aged bridges, the preventive maintenance of deck protection member is required to prevent the infiltration of the harmful water and chemicals.



(a) A bridge on Yeongdong expressway (9yrs old)



(b) A bridge on Kyeongbu expressway (38yrs old)

Figure 9 Deterioration tendency according to bridge ages

3.3 **Comparison between Survey Results**

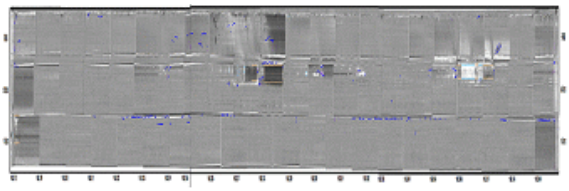
The inspection results described in Article 3.1 and 3.2 is summarized in Table 3. As shown in the table, the most of bridge decks showed a larger deterioration area when inspected with the GPR system than when inspected by visual. For these reasons, the number of bridge decks with the grade "e" by GPR inspection was more than those by visual inspection. In other words, damages of bridge deck under the overlay can be present and progressing without any symptom.

Figure 12 and 13 show inspection results of a bridge on Jungbu Expressway. Even though both locations of C1 and C2 had the good appearances, GPR system showed results corresponding to the deck truth data. The bridge deck under overlay was deteriorated at C2 but not at C1.

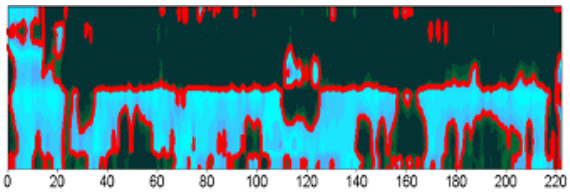
Figure 14 shows the deterioration rate by both of visual survey and GPR survey. Both show that the deterioration rate was relatively high on the 2nd lane where the heavy vehicles frequently pass over.

Table 3 Comparison of bridge surface and inner deck condition (unit : ea.)

Condition Grade	Total	a	b	c	d	e
Visual Survey	32	0	6	18	6	2
GPR Survey	32	0	4	9	4	15

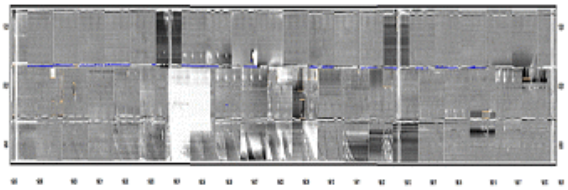


(a) Visual survey (deterioration area : 66m^2)

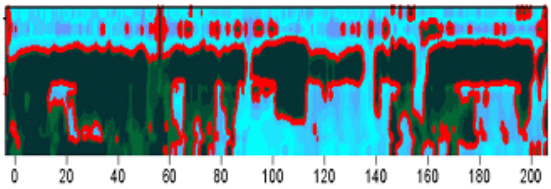


(b) GPR survey (deterioration area : 952m^2)

Figure 10 Comparison of survey results of a bridge on Yeongdong expressway

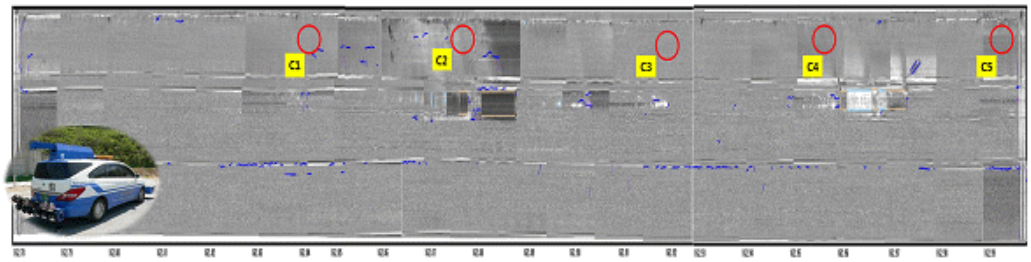


(a) Visual survey (deterioration area 96m^2)

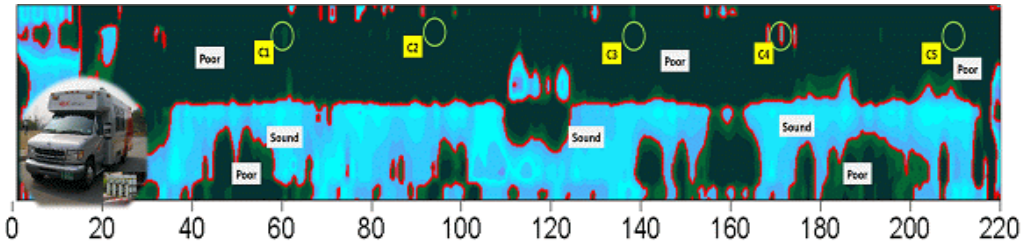


(b) GPR survey (deterioration are 864m^2)

Figure 11 Comparison of survey results of a bridge on Jungbu expressway



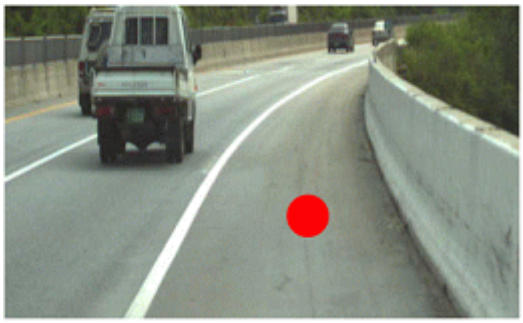
(a) Visual survey (deterioration area 66m^2, rate 3%)



(b) GPR survey (deterioration area 1148m$_2$, rate 61%)

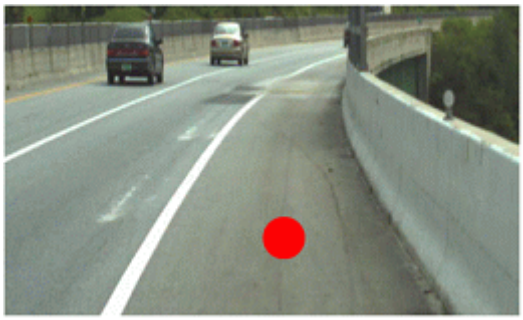
Figure 12 Comparison of survey results of bridge S on Jungbu expressway

(a) C1

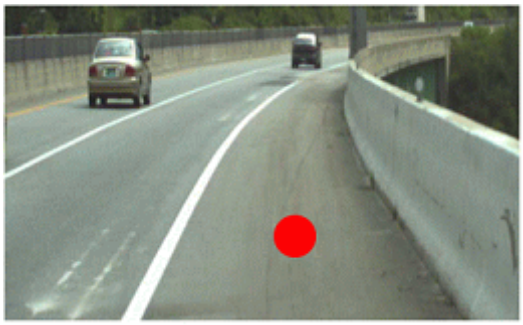


(b) C2

(c) C3



(d) C4



(e) C5

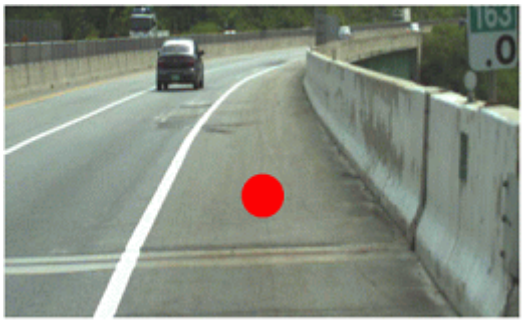


Figure 13 Real data of bridge S on Jungbu expressway

The road inspection system could be effectively available to achieve the surface condition evaluation of many bridges on South Korean expressway. However, the condition of concrete deck with overlay cannot accurately be determined by the appearance of bridge surface. Therefore, for efficient bridge deck maintenance, GPR system as well as visual inspection should be used to inspect the concrete bridge deck with asphalt overlay.

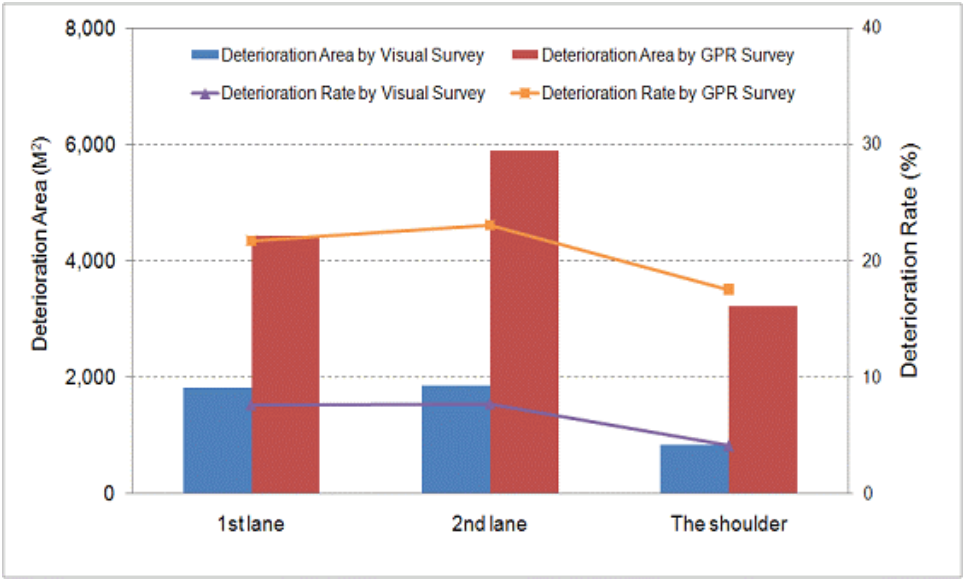


Figure 14 Comparison of deterioration for each lane

4. **CONCLUSIONS**

1. Recently in South Korea, the deterioration of concrete bridge decks with asphalt overlay had been frequently occurred on Expressway. That can be visually detected only after the internal concrete under overlay was severely deteriorated.
2. The GPR system mounted on vehicle can efficiently be used to inspect and evaluate the condition of concrete deck with asphalt overlay without intrusive traffic.
3. It is desirable that GPR vehicle system as well as visual inspection should be used for the efficient maintenance of the concrete bridge deck with asphalt overlay

REFERENCES

1. Jin-Won JUH, Ji-Young Rhee, The Analysis of Damaged Concrete of Bridge Decks by Petrographic Examination, Annual Conference, pp. 3307~3310, Korean Society of Civil Engineers, Korea, 2008
2. 阪神高速道路公団, 道路橋ＲＣ床版のひびわれ損傷と耐久性, pp.3~8, 阪神高速道路管理技術センター, Japan, 1991
3. Jin-Won JUH, Ji-Young Rhee, The Condition Evaluation of Concrete Bridge Decks using GPR mounted on Van, Vol.9 No.3, pp.29~37, Korea Institute for Structural Maintenance Inspection, Korea, 2005